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CENTRIFUGAL EXTRACTOR WITH MAGNETIC CLUTCH FOR CHEMICAL PRODUCTIONS

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Two alternative designs of a hermetically sealed extractor, the drive of which utilizes a cylindrical magnetic clutch, are examined. In the first version, the driving half coupling is internal, and the driven half coupling external. In the second version, the driving half coupling is external, and the driven internal. It is shown that as the extractor based on the first design begins to accelerate with use of a frequency regulator that permits smooth variation in current frequency, the maximum angle of mismatch between the half couplings of the magnetic clutch is less then 0.5π rad. The proposed design of the extractor has been tested at an establishment manufacturing radiochemical products, and placed in experimental-industrial service.

Extraction is one of the basic critical production processes at chemical and radiochemical establishments. Centrifugal extractors allow for significant improvement in mass-exchange characteristics of the process, acceleration and optimization of the process, and compact layout of the extraction equipment. The extractor is distinguished by a short contact time between the working solution and organic extractant. Until recently, use of this equipment in radiochemical-production processes had been suppressed due to the destructive effect of radioactive radiation on the seals, lubrication, and electric motor. The building of a centrifugal extractor with high mass-exchange characteristics, which ensures serviceability under these conditions, is therefore critical.

Centrifugal extractors in which an asynchronous motor is employed as the drive, and the support assemblies for the rotor of which are built on journal bearings formed from silicide graphite, have been developed for solution of this problem. Airtightness of the extractor is provided by a magnetic clutch that transfers rotational movement from the driven half coupling via a dividing partition (shield), which hermetically separates the effective chamber of the extractor from the surrounding medium [1].

Two versions of the cylindrical magnetic clutch are possible:

1) the driving half coupling is internal, and the driven half coupling external (Fig. 1); and

2) the driving half coupling is external, and the driven internal (Fig. 2.).

In designs of hermetically sealed machines and vessels, the outer half coupling is traditionally the driving coupling. The alternative scheme with the magnetic couplings positioned differently than in the traditional arrangement was selected in this study.

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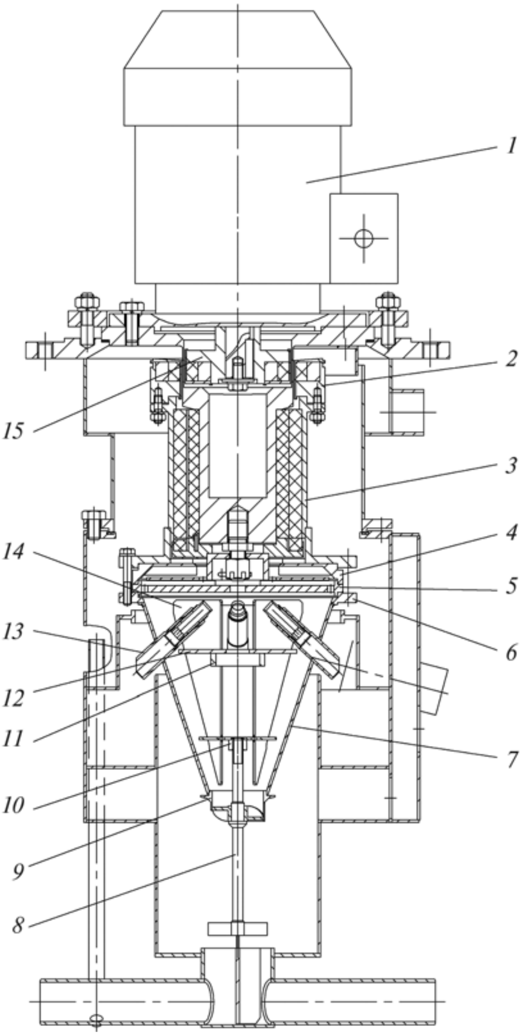

Fig. 1. General appearance of extractor with internal driving magnetic half coupling: *1*) electric motor; *2*) driven magnetic half coupling; *3*) column; *4*) cover; *5*) disk; *6*) flange of housing; *7*) conical shell; *8*) shaft; *9*) lower bushing; *10*, *11*) bushings; *12*) partition; *13*) tubes; *14*) blades; *15*) driving magnetic half coupling.

An asynchronous Model AIR71V4U3 electric motor having the following technical characteristics was employed as the electric drive motor:

Nominal power P_{2nom}, W	750
Synchronous rotational speed n_s, rps	25
Nominal slip S_{nom}, %	10
Nominal rotational speed $n_{nom} = n_s(1 - S_{nom})$, rps	22.5
Ratio of maximum to nominal torque of electric motor $m_k = M_{e.max}/M_{nom}$ . . .	2.2
Moment of inertia of rotor of electric motor $J_{e.r}$, kg·m^2	0.0014
Nominal torque of electric motor $M_{nom} = 0.159P_{2nom}/n_{nom}$, N·m	5.3
Maximum torque of electric motor $M_{e.max} = m_k M_{nom}$, N·m	11.66
Maximum transmitting torque of magnetic clutch M_{max}, N·m	16.6

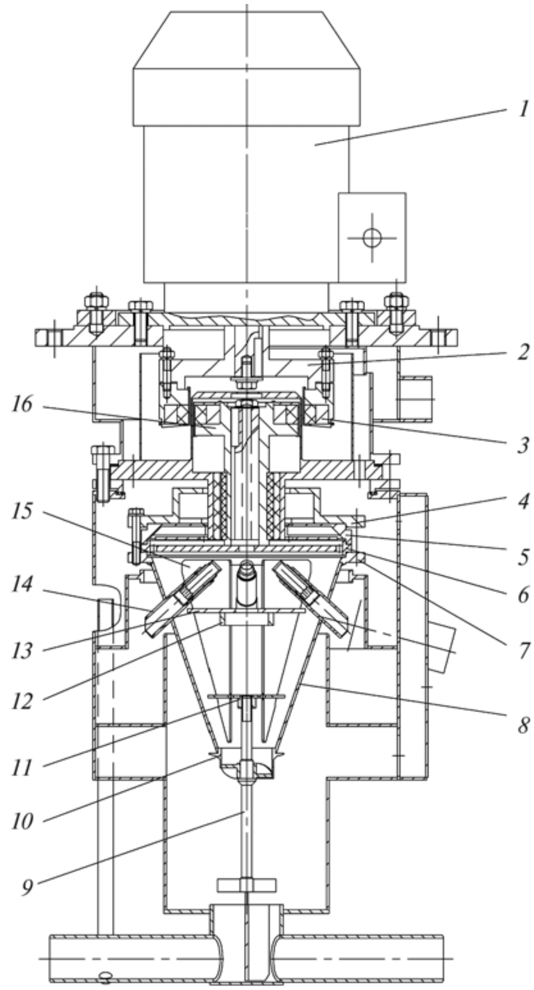

Fig. 2. General appearance of extractor with external driving magnetic half coupling: *1*) electric motor; *2*) adapter; *3*) driving magnetic half coupling; *4*) column; *5*) cover; *6*) disk; *7*) flange of housing; *8*) conical lining; *9*) shaft; *10*) lower bushing; *11*, *12*) bushings; *13*) partition; *14*) tubes; *15*) blades; *16*) driven magnetic half coupling.

The maximum angle of mismatch between the half couplings, which should be less than 0.5π can be calculated from the expression (disregarding the effect of the braking torque of the shield and load on the shaft of the extractor)

$$\Delta\alpha_{\max} = \frac{0.85}{(I_1 / I_2)^{0.6} (M_{\max} / M_{\mathrm{e.max}})^{1.2}}, \tag{1}$$

where I_1 and I_2 are the moments of inertia, respectively, of the driving and driven parts (total) in kg·m^2.

The total moment of inertia of the driving parts includes the following moments of inertia:

- internal (driving) half couple $I_{\mathrm{half.drive}} = 0.00107$ kg·m^2;
- rotor of electric motor $J_{\mathrm{e.r}} = 0.0014$ kg·m^2, i.e., $I_1 = 0.00247$ kg·m^2.

The total moment of inertia of the driven parts includes the following moments of inertia of:

• driven (external) half coupling $I_{half.driven} = 0.00672$ kg·m^2;
• column (see Fig. 1) $I_{col} = 0.01226$ kg·m^2;
• cover $I_{cover} = 0.00349$ kg·m^2;
• disk $I_{disk} = 0.00345$ kg·m^2;
• flange of housing $I_{flan} = 0.0044$ kg·m^2;
• conical shell $I_{shell} = 0.00273$ kg·m^2;
• partition $I_{part} = 0.000114$ kg·m^2;
• bushings $I_{bush1} = 0.0000141$ kg·m^2 and $I_{bush2} = 0.0000286$ kg·m^2;
• lower bushing $I_{l.bush} = 0.0000294$ kg·m^2;
• tubes $I_{tubes} = 0.00047$ kg·m^2;
• blades $I_{blades} = 0.00166$ kg·m^2, i.e., $I_2 = 0.03536$ kg·m^2; and
• the moment of inertia of the shaft and the moment of inertia of the mixer are assumed equal to zero.

Substituting I_1, I_2, M_{max}, and $M_{e.max}$ in Eq. (1), we obtain the maximum angle of mismatch $\Delta\alpha_{max} = 2.75$ rad = = 0.874π rad. At the time that the extractor begins to accelerate (direct start-up), consequently, mismatch will occur between the half couplings of the magnetic clutch, and it will not transfer torque, inasmuch as $\Delta\alpha_{max} > 0.5\pi$ rad.

To avoid this, the asynchronous motor is started using a frequency regulator permitting smooth variation current frequency to prevent slippage of the driving half coupling (internal) with respect to the driven half coupling (external); here, the critical torque of the electric motor $M_{e.max}$ remains constant.

The maximum angle of mismatch between the half couplings of the magnetic clutch during this start-up acceleration is calculated from the expression

$$\Delta\alpha_{max} = \arcsin(M_{e.max}/M_{max}) = \arcsin(11.66/16.6) = 0.779 \text{ rad} = 0.25\pi \text{ rad}. \tag{2}$$

When the extractor is operating, the half couplings of the magnetic clutch rotate, and the separating partition (shield) remains in place. Eddy currents, which result in losses of power that amount to $P_s = 129$ W in the current-conducting weakly magnetic steel 12Kh18N10T shield are induced under the action of a variable magnetic field in the shield [2].

The braking torque of the current-conducting shield is calculated from the formula

$$M_s = 0.159P_s/n_{nom} = 0.159\cdot 129/22.5 = 3.38 \text{ N·m}. \tag{3}$$

The increase in the maximum angle of mismatch between the half couplings under the braking torque of the shield will be

$$\Delta\alpha_s = 0{,}125M_s/M_{nom} = 0.125\cdot 3.38/5.3 = 0.08 \text{ rad} = 0.025\pi \text{ rad}. \tag{4}$$

As the extractor begins to accelerate, the blower torque, the value of which should be lower than, or equal to the rated torque of the electric motor, develops on the shaft, i.e., we can assume $M_{del} = M_{nom}$.

The increase in the maximum angle of mismatch between the half couplings under the action of the blower torque on the shaft of the extractor will be

$$\Delta\alpha_{del} = 0.27\frac{M_{del}}{M_{nom}(1.2)^L} = \frac{0.27}{1.2^{3.13}} = 0.153 \text{ rad} = 0.049\pi \text{ rad};$$

$$L = M_{max}/M_{nom} = 16.6/5.3 = 3.13. \tag{5}$$

Considering Eqs. (2), (4), and (5), the maximum angle of mismatch between the half couplings:

$$\Delta\alpha'_{max} = \Delta\alpha_{max} + \Delta\alpha_s + \Delta\alpha_{del} = 0.779 + 0.08 + 0.049 = 0.908 \text{ rad} = 0.289\pi \text{ rad}. \tag{6}$$

The maximum angle of mismatch between the half couplings calculated from (6) does not exceed 0.5π rad, i.e., breaking of the magnetic bond between the couplings of the magnetic clutch will not occur as the extractor begins its acceleration.

In the case when an extractor with the traditional arrangement of half couplings of the magnetic clutch is used (see Fig. 2), the total moment of inertia of the driving parts includes the following moments of inertia:

- outer (driving) half coupling, $I_{\text{half.drive}} = 0.00672$ kg·m^2;
- partition $I_{\text{part}} = 0.00492$ kg·m^2; and
- rotor of electric motor $J_{\text{e.r}} = 0.0014$ kg·m^2, i.e., $I_1 = 0.01304$ kg·m^2.

The total moment of inertia of the driven parts $I_2 = 0.02622$ kg·m^2.

The maximum angle of mismatch between the half couplings of the magnetic clutch is calculated from expression (1), disregarding the effect of the braking torque of the shield and the load on the shaft of the extractor $\Delta\alpha_{\max} = 0.846$ rad $= 0.27\pi$ rad.

The values of the additions calculated from expressions (4) and (5) are in agreement.

The maximum angle of mismatch between the half couplings during direct start-up without use of the frequency regulator:

$$\Delta\alpha'_{\max} = \Delta\alpha_{\max} + \Delta\alpha_s + \Delta\alpha_{\text{del}} = 0.846 + 0.08 + 0.049 = 0.975 \text{ rad} = 0.31\pi \text{ rad}. \quad (7)$$

Thus, fail-safe operation of the extractor during its initial acceleration is ensured, since $\Delta\alpha'_{\max} < 0.5\pi$ rad.

As compared with the design of the extractor in Fig. 2, the design of the extractor in Fig. 1 has smaller clearance dimensions, and the slip bearing, which is secured in column *3* (see Fig. 1), possesses maximum possible dimensions. These factors determined the selection of this design for subsequent fabrication and testing under industrial conditions.

The design proposed for the extractor (see Fig. 1) was tested at establishments manufacturing radiochemical products, and is currently in experimental-industrial service. During its operation, no shutdowns due to poor working condition of the magnetic clutch have been observed.

Conclusions

1. The design of an extractor with an internal driving half coupling is reliable.

2. A frequency regulator must be used to provide for smooth start-up of the asynchronous electric motor (reliability of the magnetic bond between the half couplings).

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